Report of the iMOST Study

May 31, 2018

International MSR Objectives and Samples Team (iMOST)

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Notes

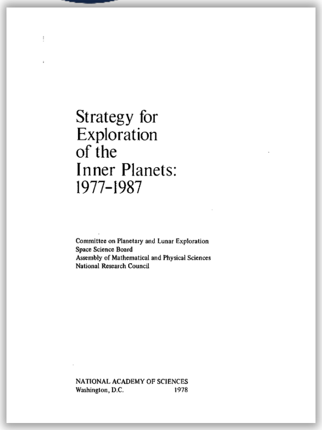
- *An earlier version of this PPT flie was presented and discussed at the 2nd International Mars Sample Return Conference, in Berlin, Germany, April 25-27, 2018. This version incorporates feedback received.*
- *This document is the PPT representation of a large text-formatted report (working title: "The Potential Science and Engineering Value of the Samples that Could be Delivered to Earth by Mars Sample Return"). In case of discrepancies, the text report should be interpreted as superior.*
- *This study was sponsored by the International Mars Exploration Working Group (IMEWG).*

Introduction to This Study

- The iMOST study was chartered in November, 2017 by the International Mars Exploration Working Group (IMEWG) to assess the **expected value of the samples** to be collected by the M-2020 rover. Included is a request to:
  - **Update the proposed scientific objectives** of Mars Sample Return (MSR)
  - Map out the **kinds of samples** that would be desired/required to achieve each of the objectives, and the implied **measurements** on the returned samples
- Guided by the science community's already established priorities for Mars science
- The existence of the M-2020 sample-caching rover, and the interest of key space agencies in completing the transportation missions of MSR, makes the forward planning scenarios **much more specific and tangible**.

History of Scientific Support for MSR

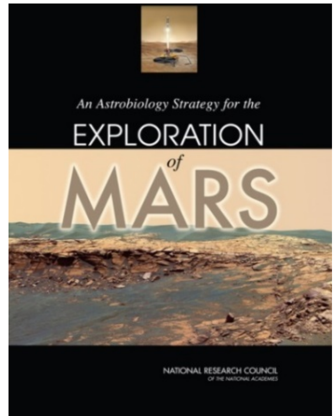
International MSR Objectives & Samples Team

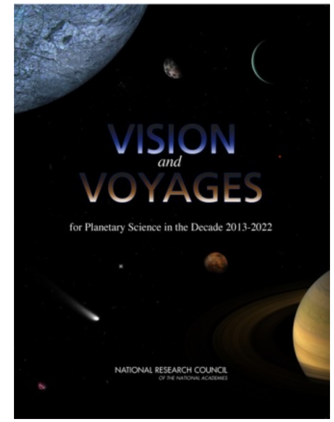

Strategy for
Exploration
of the
Inner Planets:
1977–1987

Committee on Planetary and Lunar Exploration
Space Science Board
Assembly of Mathematical and Physical Sciences
National Research Council

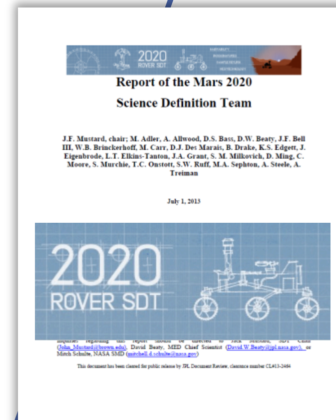
NATIONAL ACADEMY OF SCIENCES
Washington, D.C. 1978

Inner Planets, 1977





Dec. Sur., 2011



M-2020 SDT, 2013

1980 1990 2000 2010 2020

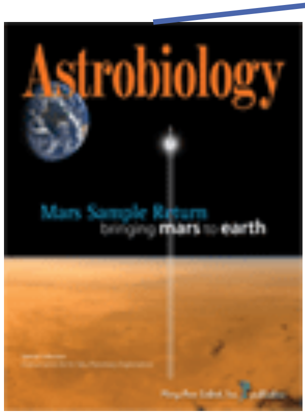
ND-SAG 2008

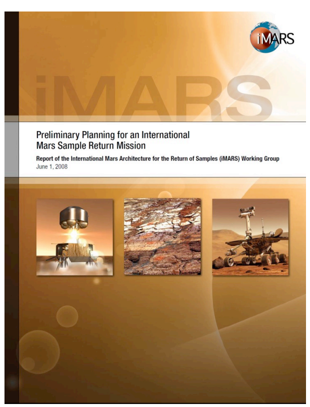
iMARS-1 2008

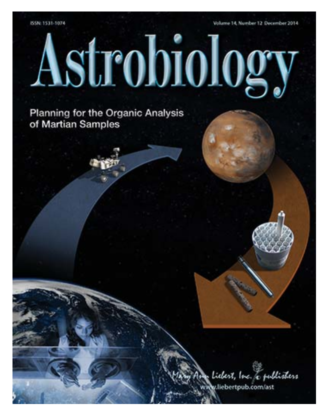
E2E-iSAG 2011

OCP 2014

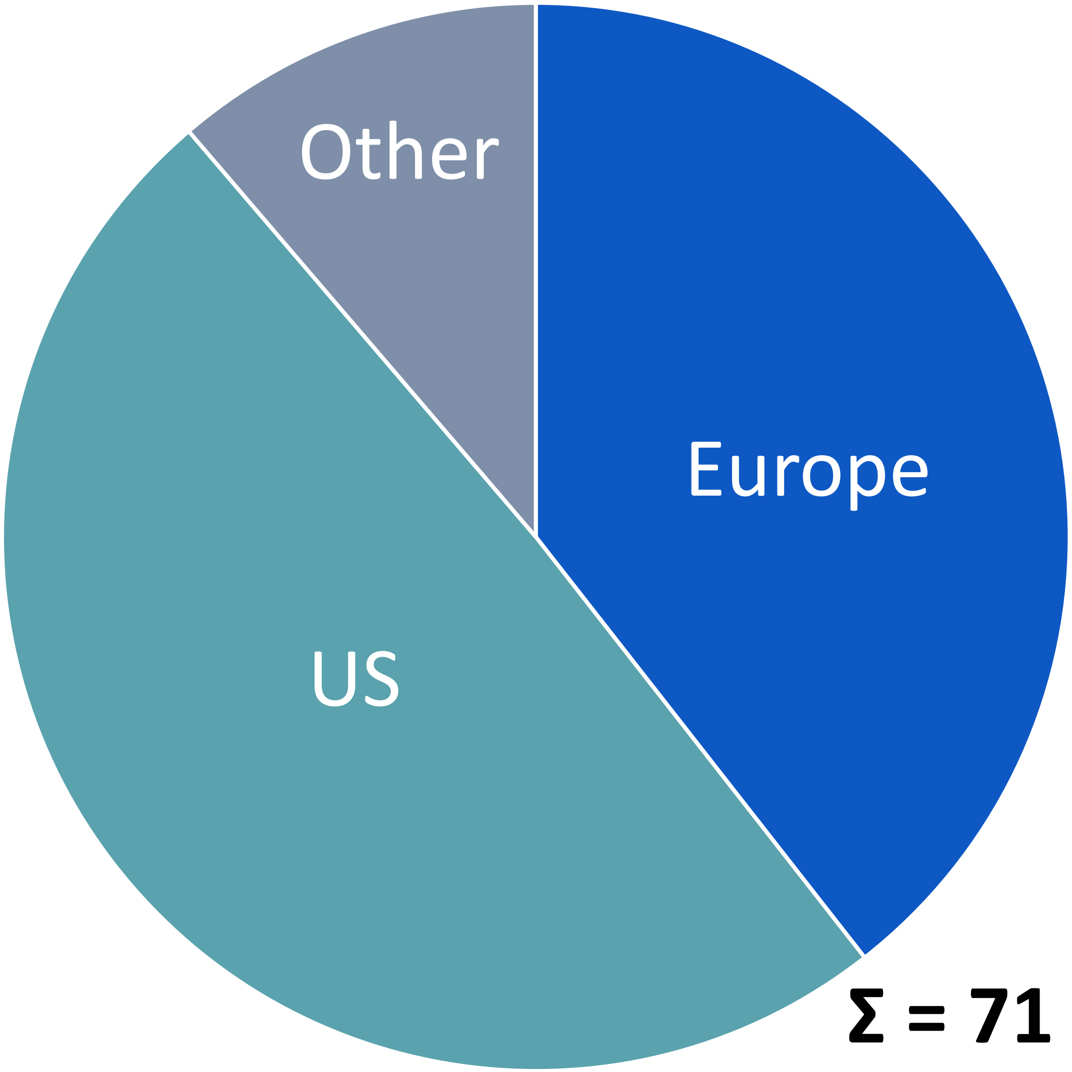
iMARS-2 2016







International Participation, iMOST Study



$\Sigma = 71$

Countries Represented	
Australia	Netherlands
Belgium	Norway
Canada	Spain
France	Sweden
Germany	Switzerland
Italy	UK
Japan	US
New Zealand	

Science of MSR : What Has Changed?

- The expected value of the samples needs to be updated in light of the following:
  - Progress in the study of **Mars meteorites** (the number and diversity has increased from 55 in 2011 to >100 today)
  - **New mission results:** from Mars.
    - Curiosity & MER rovers. Now approaching 26 combined years of ops; key results in habitability/preservation potential)
    - Mars orbiters: MRO, MEx, ODY
  - **Astrobiology:** Significant improvements in our understanding of the potential for the preservation of the signs of life in the geologic record, and how to translate that to specific times/places on Mars
  - **Planning for Human Exploration:** Improved understanding of the ways returned sample studies would reduce the risk of a future human mission
  - **Instrument Developments:** Better ability to handle and analyze very small samples
  - **Sample Quality Attributes:** now known

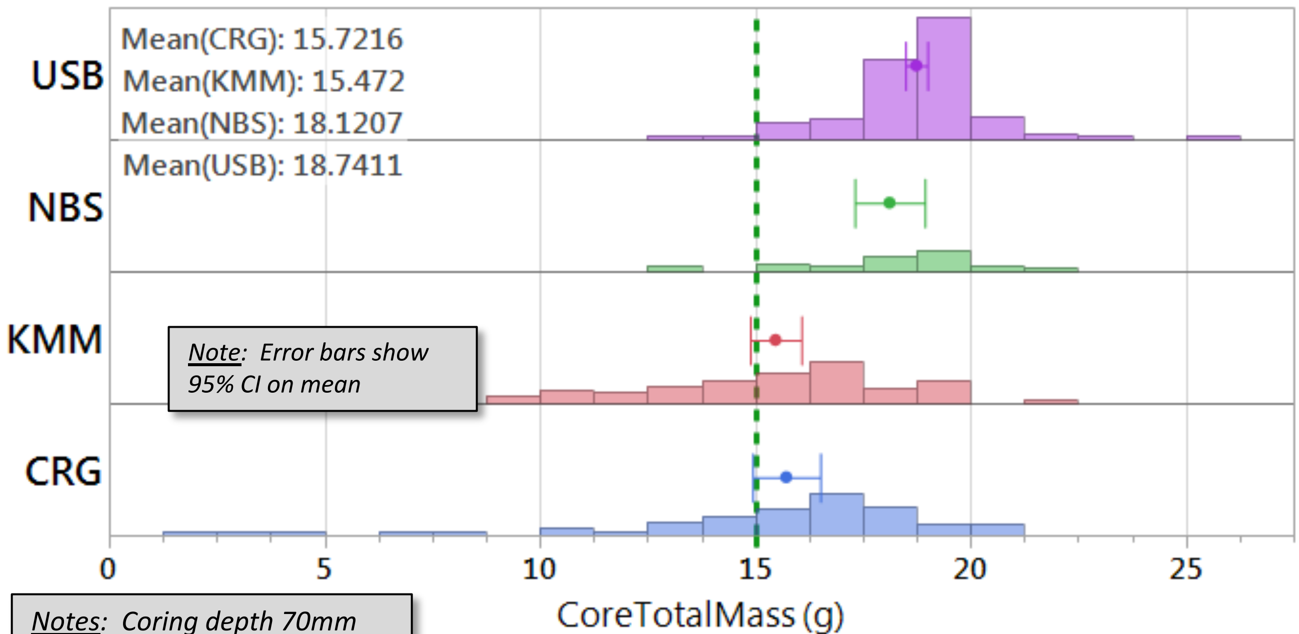
Assume: Samples will be High Quality

- **Sample quality attributes established** using M-2020 RSSB and several precursors (2014-17), PP and Advance Planning.

- All factors translated into **requirements**, and have been adopted by M-2020 and have flowed into MSR Advance Planning teams.

Sample Quality Parameter	Recommended Requirement
Biologic Contamination	<1 viable terrestrial organism per tube
Organic Contamination	Tier 1 compounds <1 ppb Tier 2 compounds <10 ppb TOC <40 ppb
Inorganic Contamination	Group A <1% Group B <0.1% Pb <2 ng/g
Magnetics	Exposure to <0.5 mT Shock pressure <0.1GPa Orientation to half-cone uncertainty of <5°
Fracturing	Size distribution in a single core of <20% by mass in pieces ≤2 mm, and >70% by mass in pieces with largest dimension >10 mm
Internal Movement	Minimize by preloading tubes compatible with X-ray CT imaging of core before removal
Temperature	<60 °C required, <40 °C desired
Cross-Contamination	<150 mg per samples tube
Sealing	<1% water, translated to He leak rate for 20 years
Radiation	<100 krad over 20 years

Sample Mass



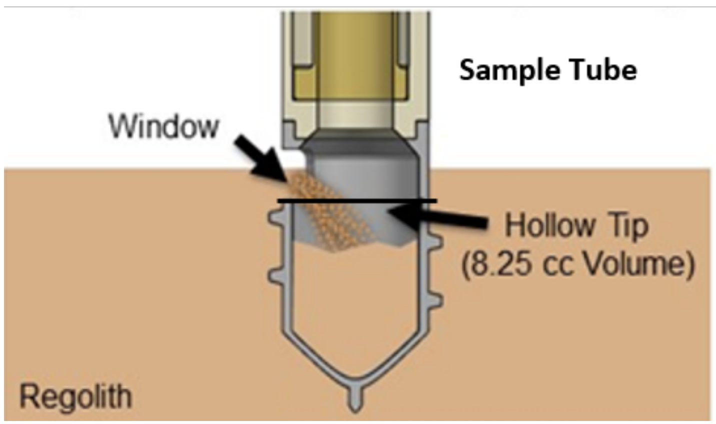
Notes: Coring depth 70mm

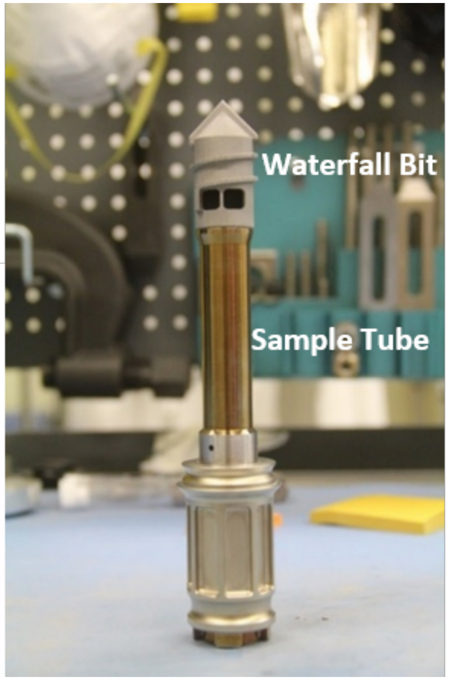
REGOLITH

- *Can collect 8 cm3 of regolith material*
- *Using ρ of about 1.15 g/cm3, ~9.5 gm of sample*

ROCK

- *Average sample mass in tests is 16.5g*
- *90% of samples are ≥ 13.4g*
- *Rock cores < 5g are considered engineering failures*





Proposed Sample-Related Objectives from the 2018 iMOST Study

Objective	
1	*Geological environment(s)*
2	*Life*
3	*Geochronology*
4	*Volatiles*
5	*Planetary-scale geology*
6	*Environmental hazards*
7	*ISRU*

Sub-Objective
Sedimentary System
Hydrothermal
Deep subsurface groundwater
Subaerial
Igneous terrane
Carbon chemistry
Biosignatures--ancient
Biosignatures--modern

Structure of the Information

Introduction & Current State of Knowledge

KEY OPEN QUESTIONS: SUB-OBJECTIVE 1.1
What was the character, diversity, geological history and age of the provenance region for the sediment that accumulated in any given martian depositional basin?
How was sediment generated on Mars and has that changed over geological time?
What was the history, including timing, quantity, and chemistry, of widespread surface and near-surface water on Mars and how is the … sediments?
What was the nature of water-related …
How did the many possible processes …
What is the nature of martian aeolian …
Do martian sedimentary rocks record t… chemistry?

Key Open Questions & Why Returned Sample Studies are Needed

Investigation Strategies (IS) for Objective 1 Sub-Objective 1.1		
1	Geological environment(s)	Interpret the primary geologic processes that formed and modified the pre-Amazonian martian geologic record.
1.1	Sedimentary System	Understand the essential attributes of a martian sedimentary system.
IS 1.1A		Investigate physical and chemical sedimentary processes in standing or ponded water to understand more completely the occurrence of sustained, widespread liquid surface water on Mars, including the examination of evaporites resulting from such processes.
IS 1.1B		Investigate sediment diagenesis, including the processes of cementation, dissolution, authigenesis, recrystallization, oxidation/reduction, and fluid-mineral interaction.
IS 1.1C		Investigate the mechanisms by which sediment is/was generated on Mars, by understanding the weathering and erosional p…
IS 1.1D		Investigate the provenance… lithology, tectonic associati…
IS 1.1E		Investigate the nature of su… valleys, including whether t… conditions and timescales o…
IS 1.1F		Characterize the physical pr… processes and climate histo…

Investigation Strategies

Samples identified to advance Investigation Strategy 1.1C:

- Rocks of any type that show a range of weathering styles and weathering intensity, including weathering rinds, if present.
- Sedimentary rocks with a variety of grain compositions.
- Modern regolith, especially if locally derived.

Measurements identified to advance Investigation Strategy 1.1C:

- Determine the minerals formed by the weathering process over a range of distinct parent lithologies.
- Determine the mi… relationship to the…
- Determine the pr… rocks (and associa… minerals that can…

Samples and Measurements

UNDERSTAND A MARTIAN SEDIMENTARY SYSTEM	
Why is this objective critical?	*A key input into interpreting the history of water on Mars; search for life.*
What are the most important samples?	*One or more suites of sedimentary rocks representative of the stratigraphic section, different lithification intensity and style, and coarse-grained rocks with grain diversity.*

Summary

1.1 Understand a Martian Sedimentary System

Objective	
1	*Geological environment(s)*
2	*Life*
3	*Geochronology*
4	*Volatiles*
5	*Planetary-scale geology*
6	*Environmental hazards*
7	*ISRU*

Sub-Objective
Sedimentary System
Hydrothermal
Deep subsurface groundwater
Subaerial
Igneous terrane
Carbon chemistry
Biosignatures--ancient
Biosignatures--modern

Introduction

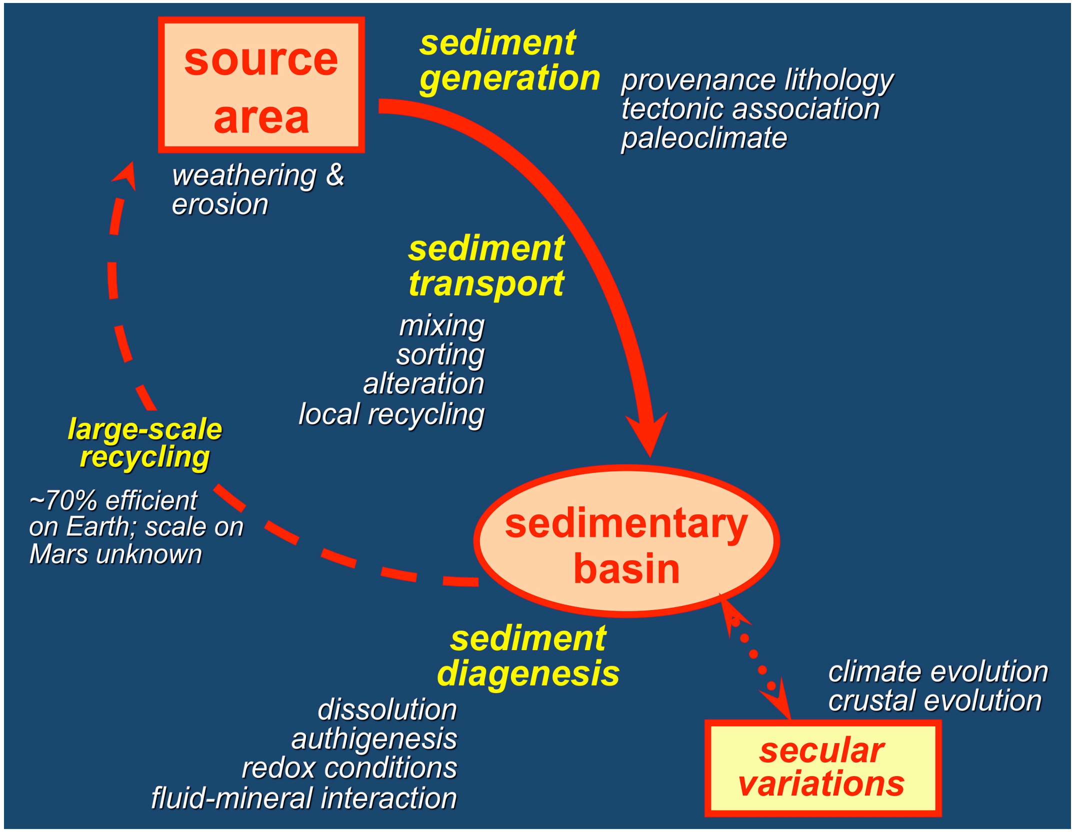
- Sedimentary rocks preserve the most continuous record of the geological history of planetary surfaces, including any history of life
- Sedimentary history is best understood in terms of “source-to-sink” processes that track sedimentary rocks:

  – from their ultimate origins (provenance)

  – through formation of sedimentary components (particulate & dissolved)

  – transport (particulate & dissolved) and deposition (clastic & chemical)

  – post-depositional changes (lithification, diagenesis, recycling…)



Introduction/Critical Open Questions

- Despite the fact that Mars missions have tracked these processes, many critical questions require more thorough analyses than is possible using orbiting and landed spacecraft

- Return to Earth of carefully selected sedimentary sample suites would be required to move substantially forward on these questions

Critical Open Questions

- What was the **history of surface water** on Mars?

  e.g., including timing, quantity, and chemistry

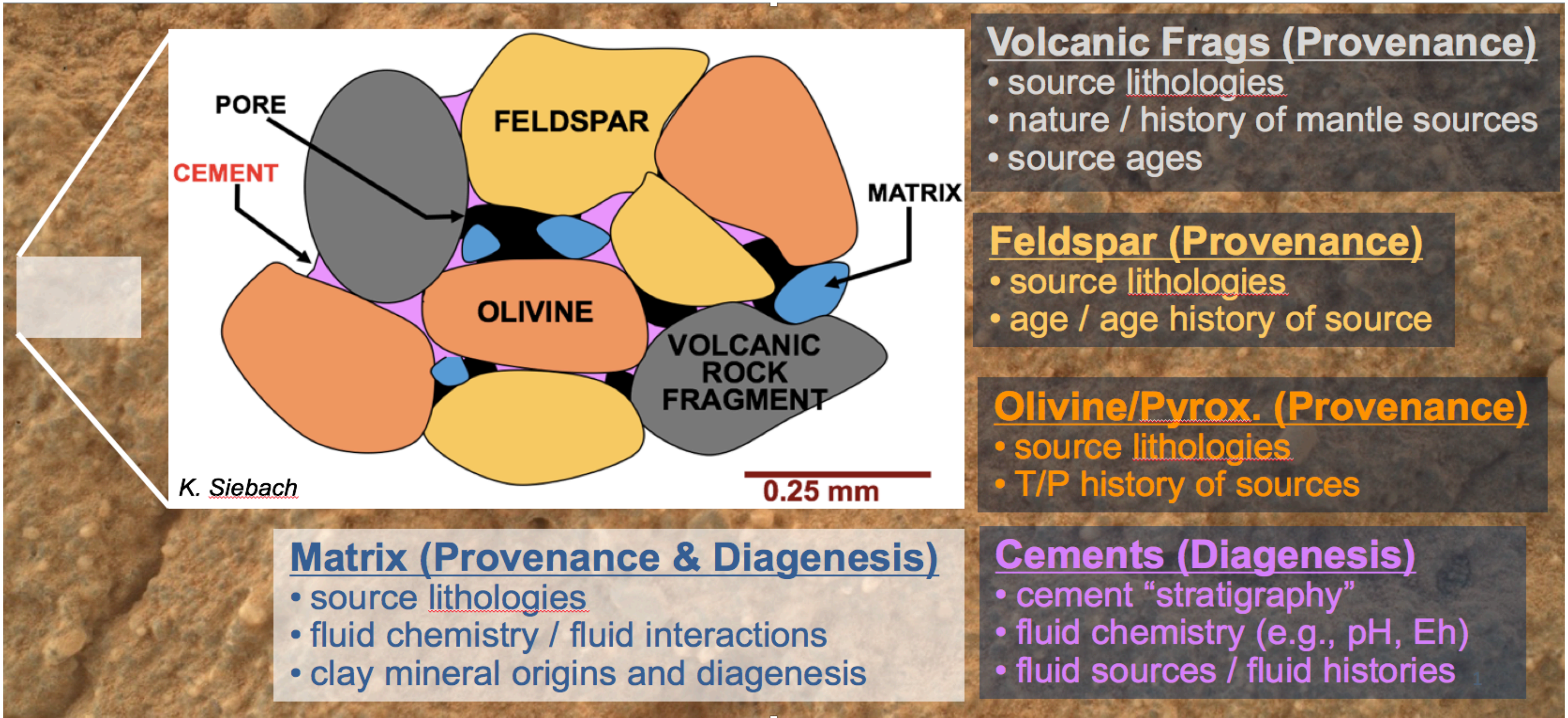
- What were the characteristics of the **provenance region(s)**?
- How did the **process of sediment diagenesis** on Mars work?
- Do sedimentary rocks record the **evidence of ancient life?**

Questions → Investigation Strategies

Sedimentary System	Understand the essential attributes of a martian sedimentary system
Invest. 1.1A	Investigate **physical and chemical sedimentary processes** in standing or ponded water to better understand sustained, widespread liquid surface water on Mars, including the examination of evaporites resulting from such processes.
Invest. 1.1B	Investigate **sediment diagenesis**, including the processes of cementation, dissolution, authigenesis, recrystallization, oxidation/reduction, and fluid-mineral interaction.
Invest. 1.1C	Investigate the mechanisms by which sediment is/was generated on Mars, by understanding the **weathering and erosional processes**.
Invest. 1.1D	Investigate the **provenance of the sediment** in the sedimentary system, including variation in lithology, tectonic association, and paleoclimate.
Invest. 1.1E	Investigate the **nature of subaqueous (or subglacial) transport regimes** that cut channels and valleys, including whether they were persistent or episodic, the size of discharge, and the climatic conditions and timescales of formation.
Invest. 1.1F	Characterize the **physical properties of aeolian materials** to understand aspects of the surface processes and climate history.

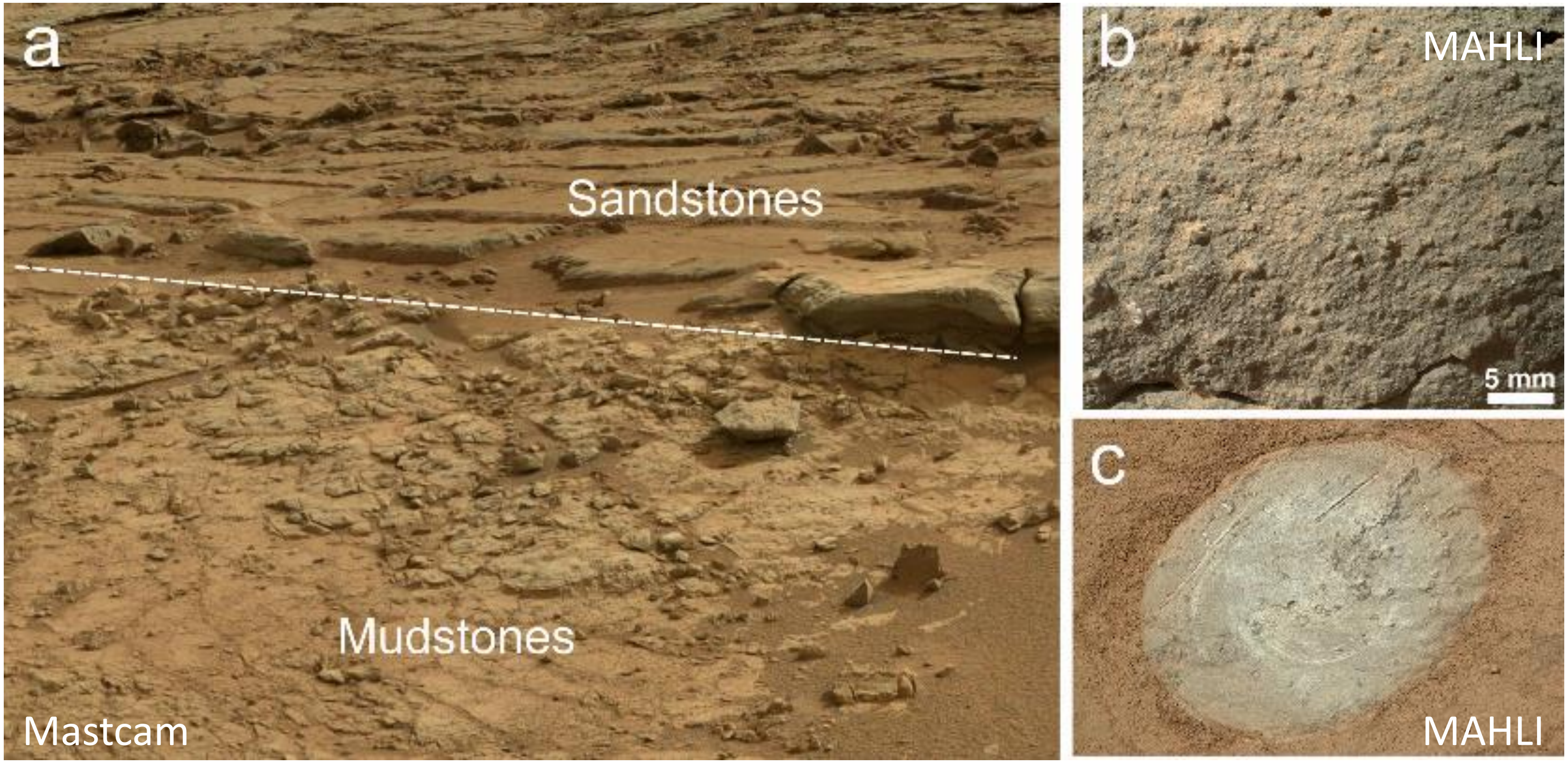
Sedimentary Provenance Analysis

- Modern sedimentary analyses rely on "**grain by grain**" studies, using the most sophisticated analytical methods, to fully understand provenance and sedimentary history
- Physically disaggregate sediment and/or use modern beam methods (e.g., SIMS, LA-ICP-MS, µXRF, etc.)



Sampling Fluvio-Lacustrine Sedimentary Rocks

- Lacustrine deposits in a quiet environment favorable to organic preservation
- Sampling a **suite of sediment types** would enable analysis of processes such as: sorting effects, cementation, input of detrital rocks, etc.



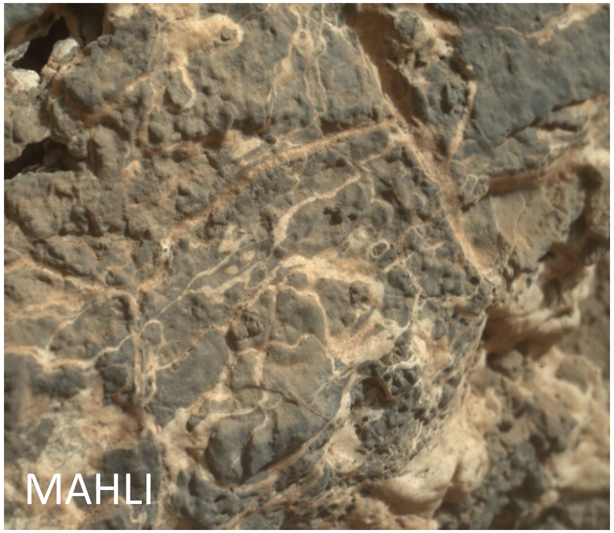
(a) Contact between lacustrine mudstones (bottom) and fluvial sandstones at Yellowknife Bay, Gale crater.
(b) Close-up on the sandstones showing cemented coarse grained deposits.
(c) Close-up on a brushed area of mudstones only displaying local concretions.

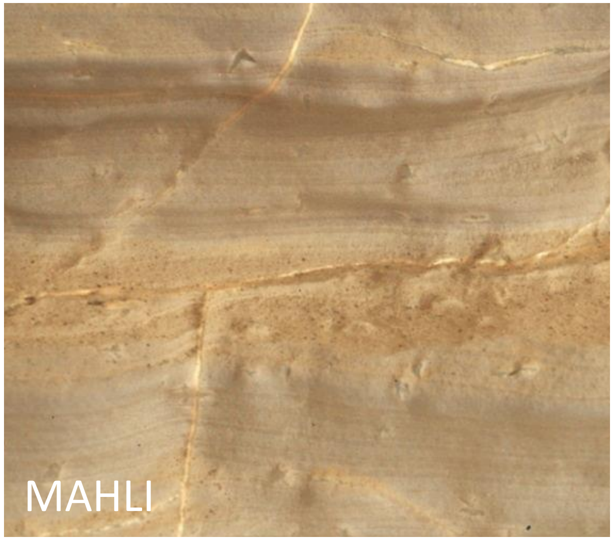
Why Returned Sample Studies are Important

- Orbital and In Situ data provide **critical geological context** for samples
- In Situ missions have demonstrated that sophisticated measurements can be obtained : e.g., quantitative mineralogy, major/trace element geochemistry, GC-MS / TLS analyses

BUT such measurements inevitably require **'follow on' analyses**

- Many key questions require further measurements that cannot be made on Mars – e.g.: - multiple radiogenic isotope techniques to obtain **reliable age dates**
  - synchrotron studies to evaluate sedimentary **amorphous components**
  - complex **organic geochemistry** analyses to evaluate 'life question'





Samples and Measurements

Summary of measurements required/desired for returned samples:

- Textural analyses (e.g., grain size / shape)
- Quantitative mineralogy and μm-scale mineral chemistry
- Major and trace elemental geochemistry
- Stable isotope geochemistry
- High resolution (micron-scale) petrographic analyses
- Geochronology using multiple isotope systems on both whole rocks and individual minerals

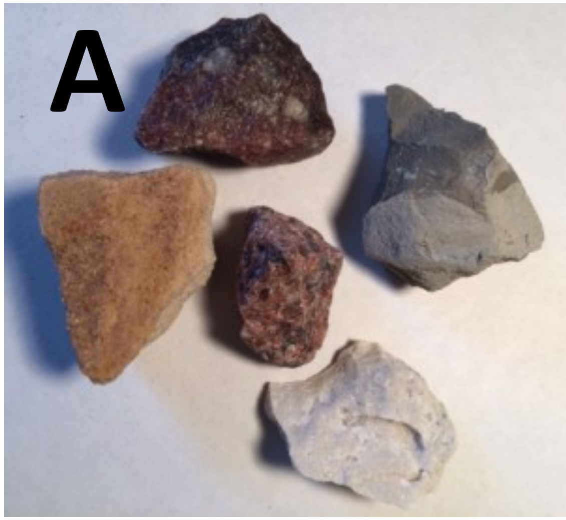
Summary of samples required/desired to achieve objectives:

- Suite of sedimentary rocks representative of selected depositional setting
- Suite of sedimentary rocks showing range of lithification and diagenetics
- Rocks showing range of weathering intensity/style, incl. modern regolith
- Sedimentary rocks with a variety of grain compositions, including relatively coarse-grained (multi-lithological) clastic sedimentary rocks.
- Samples of modern and ancient (lithified) aeolian sediment and sedimentary rocks

Conclusions

Sample Suites

- **Geologic processes generate heterogeneous products.**
- **Using sample studies to interpret geologic history/processes typically requires a sample suite that spans the range of variation, not single samples.**



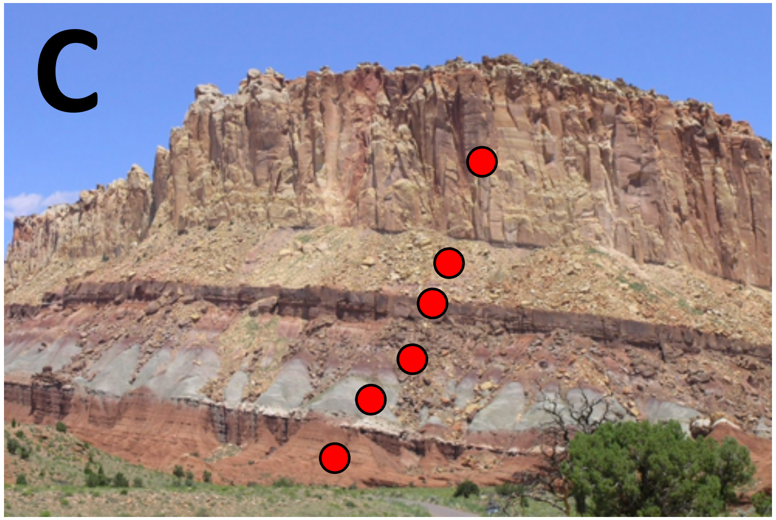
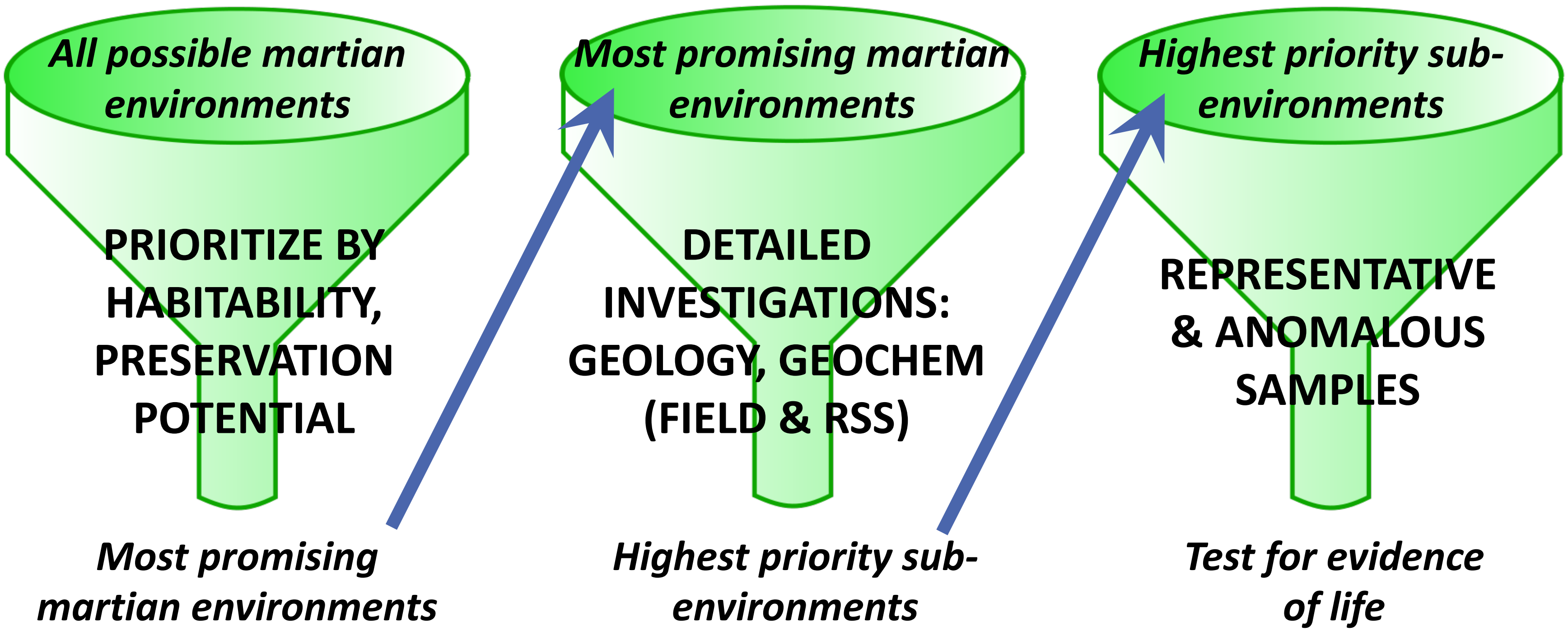


Figure caption. A primary value of suites is that they allow for study of the similarities/differences between samples. A) A suite of rocks showing some of the geologic variation in Wisconsin. B) Sample suite showing variations in sedimentary rocks on Earth. C) An example of stratified sedimentary rocks (on Earth), and the possible design of a scientifically useful sample suite.

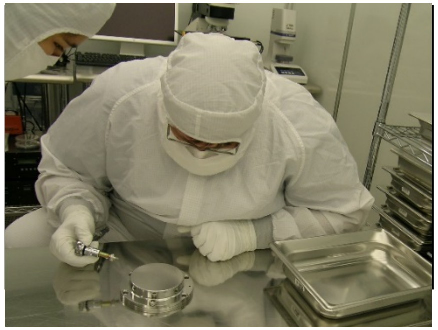
MSR Needs to Narrow the Search Space for Life



Key Message: Since we do not know exactly how evidence of martian life might be preserved in the geologic record, we need to sample a location with as much variety as possible, and it needs to be sampled carefully and systematically.

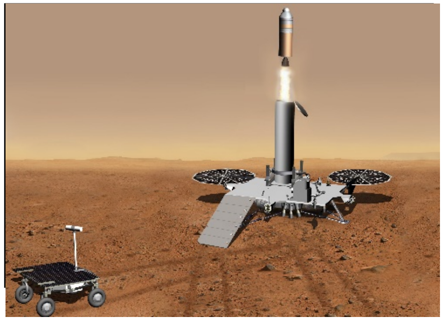
Mars Sample Return

SCIENCE



- *Civilization-scale science*
- *Samples: the gift that keeps on giving*
- *Definitive scientific results*
- *Only way to advance critical sectors of planetary science & astrobiology*

ENGINEERING



- *Unique technical challenges drive unprecedented innovation*
- *Advances will benefit future robotic and human missions.*
- *Crucible for engineering as a discipline.*

PREPARATION

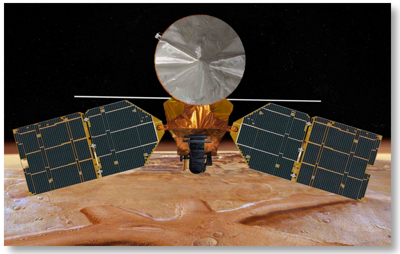
- *Prepare for humans to Mars*
- *Inform planetary protection policy evolution to enable future missions*

INSPIRATION

- *Inspire and train the next generation*
- *Magnet for international cooperation*

We have the opportunity and motivation to carry out MSR on an international basis

Why Mars Sample Return?



- Exploration of Mars to date, from orbit and from the surface, has given us incredibly **valuable insights** into many aspects of Mars.
- These insights have allowed us to pose **new, far more detailed, questions** that could not have been asked before.

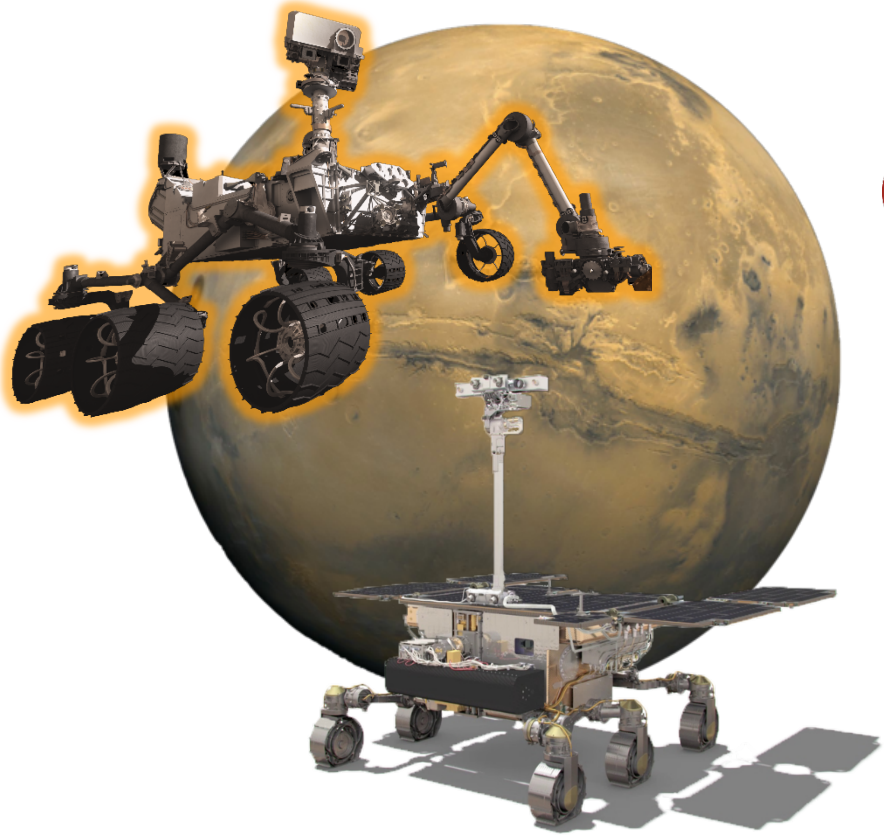
Taking the next step

- A certain set of scientific objectives can **only be achieved** with samples in a laboratory.
- For Mars, we are at the point where the scientific logic implies this **should be done next**.
- Results are expected to be **profound** (“civilization-scale” science)

Opposite Approaches for Mars Exploration

We need BOTH!

Large amounts of sample but limited instruments



Sample Return

Small amounts of sample but unlimited instruments

- Finite number and types of analyses using prescribed protocols.
- Important preliminary organic characterization steps.

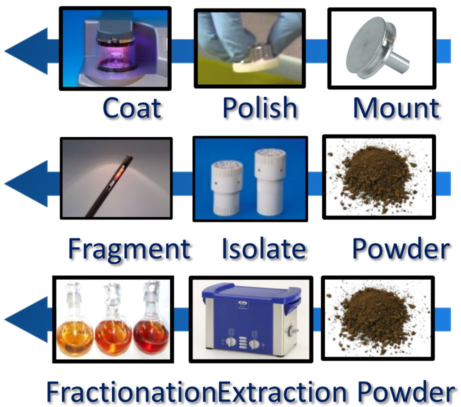
- Unlimited number of analyses with complete flexibility.
- Comprehensive organic characterization.

What Makes Laboratory Samples so Valuable?

International MSR Objectives & Samples Team

Four powerful technical advantages:

Access to sophisticated sample prep.



Organic prep. pathways

- *Reduces detection limits (by orders of magnitude)*
- *Improves precision*
- *Greater accuracy*
- *Required for many instruments*

Multiple, diverse, and large instruments that cannot be miniaturized.

- *Opportunity to make confirming measurements using multiple methods*
- *"Gift that keeps on giving" – analysis by future instruments*
- *"Extraordinary claims require extraordinary evidence"*

SEM

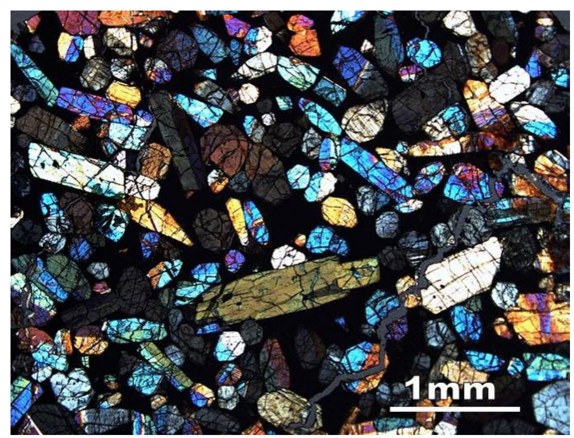
Discovery-responsive investigation pathways

- *Answers to early questions change choice/ design of later experiments*

Oolitic limestone
Cretaceous

Thin section

Greatly improves spatial focus/resolution

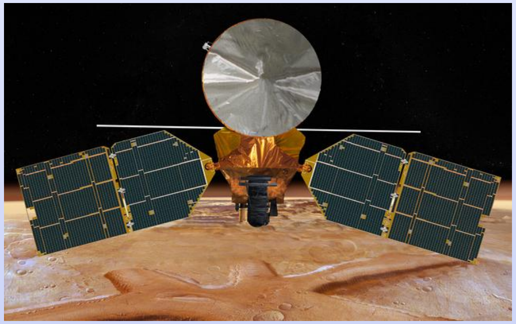


- *For evaluating microbial life, microscopic scale is crucial*
- *Access to small grains crucial*

Mars meteorite

Why MSR *now*?

STRATEGIC PLANNING



- *Highest priority of Planetary Science Decadal Survey (2012)*
- *Strategic advantage to use Mars Reconnaissance Orbiter (MRO) to support MSR mission before MRO end of life*
- *Critical technology (M2020, MAV, PP containment) is understood and ready*
- *Advancements will benefit other future missions*

SCIENCE

- *Can move the science from characterizing the environment to explaining what was/is happening at Mars today/into the future*
- *Opportunity to acquire pristine samples before human explorers potentially introduce ambiguity into Mars astrobiology investigations*

HUMAN EXPLORATION

- *Data can inform future human mission hardware concepts early in the design process, before it becomes too expensive or difficult to change*

Proposed Next Steps—Science Perspective (1 of 3)

The Potential Science and Engineering Value of Samples Delivered to Earth by Mars Sample Return

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Final Report

August 14, 2018

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iMOST (2018), The Potential Science and Engineering Value of Samples Delivered to Earth by Mars Sample Return, (co-chairs D. W. Beaty, M. M. Grady, H. Y. McSween, E. Sefton-Nash; documentarian B.L. Carrier; plus 66 co-authors), 186 p. white paper. Posted August, 2018 by MEPAG at https://mepag.jpl.nasa.gov/reports.cfm.

This report requested by the International Mars Exploration Working Group (IMEWG).

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- ~~Complete the text-formatted iMOST Report~~
- ~~Draft exists~~
- ~~Incorporate feedback from Berlin~~
- ~~Get it published~~

Proposed Next Steps—Science Perspective (2 of 3)

Fly the M-2020 sample caching rover, select/acquire compelling samples

- Landing site selection (3rd landing site workshop will be held the week of Oct. 15, 2018; JPL area)
- Need good set of sample scientists to join Project as Participating Scientists (Michael Meyer to discuss on Friday)
- Design logical, effective sample suites; establish recoverable sample cache(s)

Design/fly retrieval missions

- Prioritize samples collected by M-2020 for potential retrieval, so that logic of the suites is not lost. Carefully choose the best 31.
- Collect atmospheric sample(s)
- The retrieval missions would have at least some instruments of interest to science (cameras, T, etc.). We hope scientists are allowed to participate.

Proposed Next Steps—Science Perspective (3 of 3)

Planning related to what would happen after the samples are returned

- Planning for Sample Receiving and Curation Facilitie(s), and the activities that would take place in each.
- How the tubes would be opened, samples extracted (incl. headspace gas).
- Planning on whether and how a subset of the collection should be sterilized, so as to get some samples to external labs (SCFs).
- Curation planning (atmosphere, T, metals, contamination control, etc.)
  - If there are multiple facilities, should they store the samples under the same or different conditions?
- Planning for any specialty sample analysis instruments—e.g. that significantly reduce the sample mass needed or sample contamination?
- Planning for science funding mechanisms (international), and sample allocation processes.
- Sample Management Plan (e.g. the sequencing of samples/analyses—which measurements can make use of left-over material from a previous measurement?).
- Other?